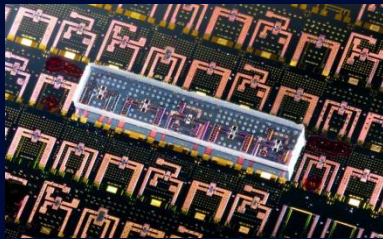


Towards a consistent thermodynamic model of magnetocaloric material from experimental characterization

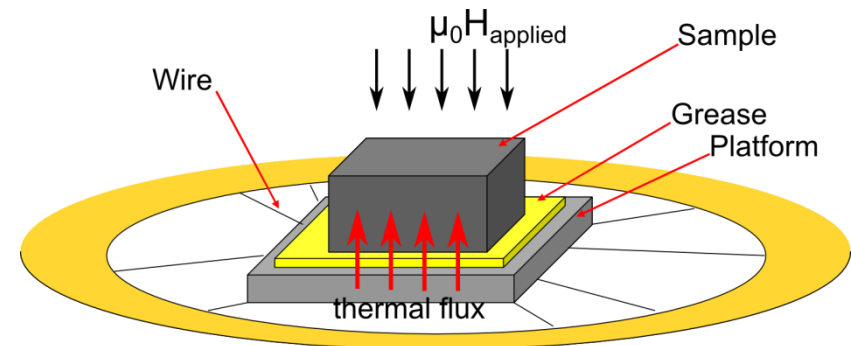
**PhD student M. ALMANZA,
A. Kedous-Lebouc, V. Hardy, S. Miraglia
G2Elab, CRISMAT, Institut Néel**



Material model

- From experiment: $\mathcal{M}(H_{applied}, T), \quad c_H(H_{applied}, T)$
- ⇒ To intrinsic properties: $M(H, T), \quad c_H(H, T)$

- Fitting and interpolation



Numerical simulation of Brayton Cycle

- Wrong estimation of COP

Understanding and new approach to improve thermodynamic consistency

COP estimation on Brayton Cycle

Magnetic method

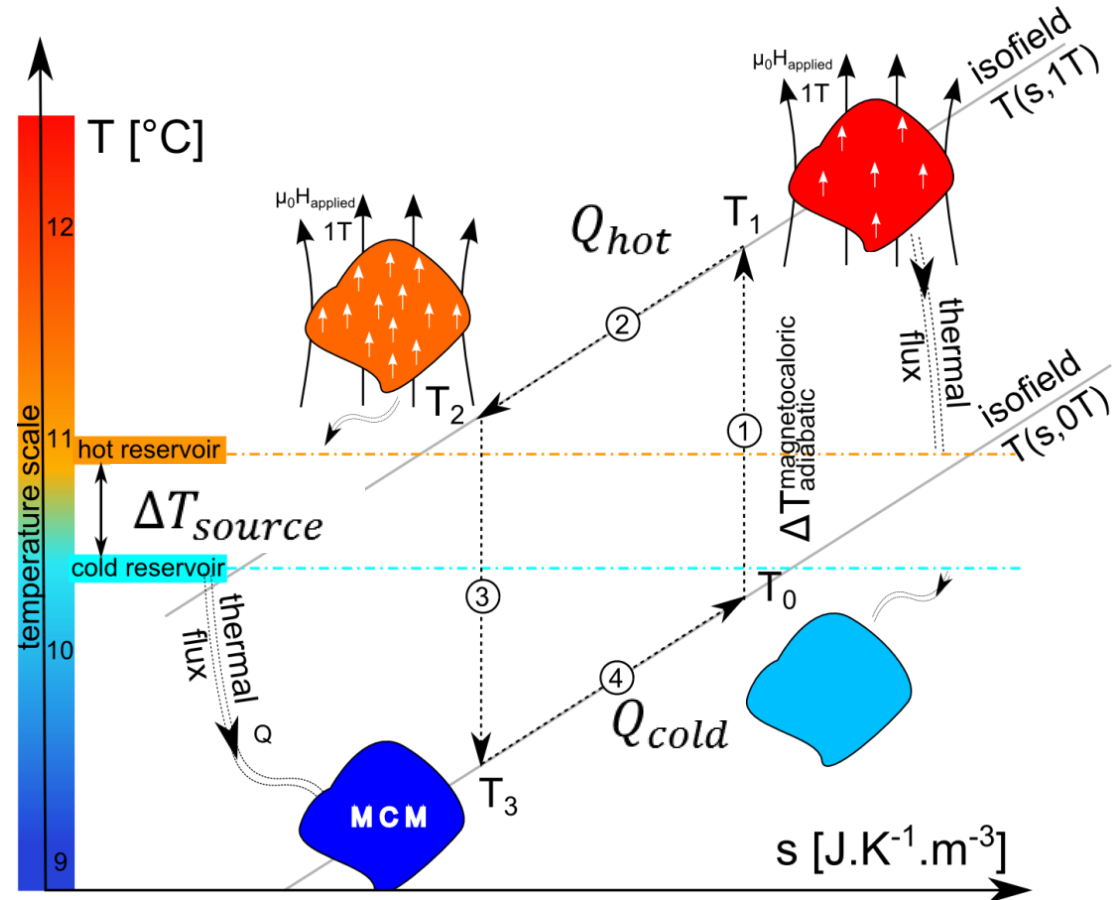
$$COP = \frac{Q_{cold}}{W_{mag}}$$

$$W_{mag} = - \int_{(1),(3)} \mu_0 M dH$$

Thermal method

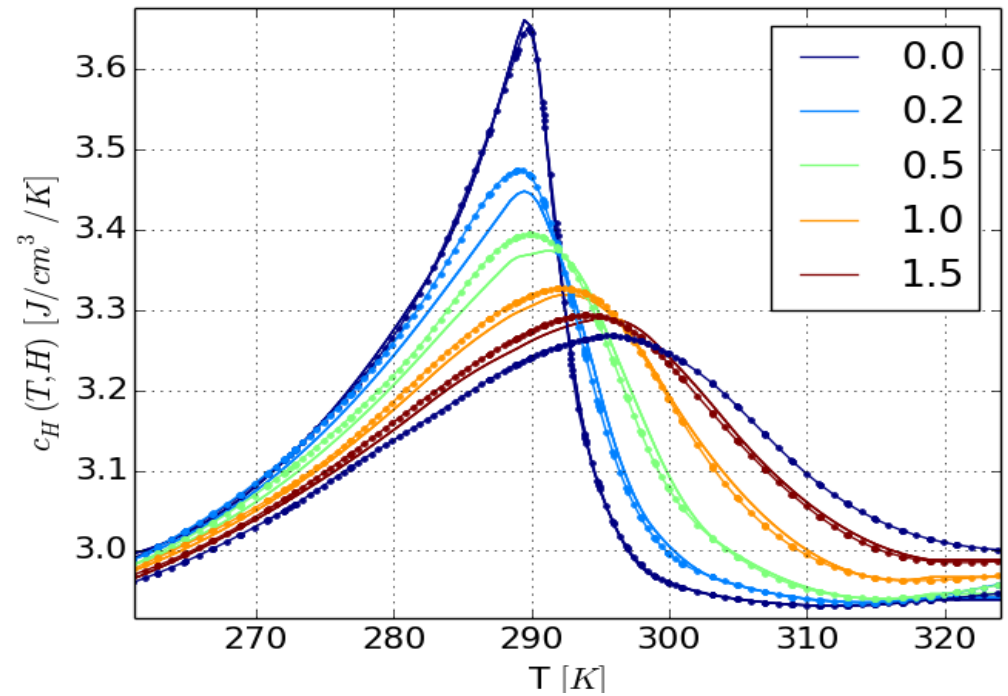
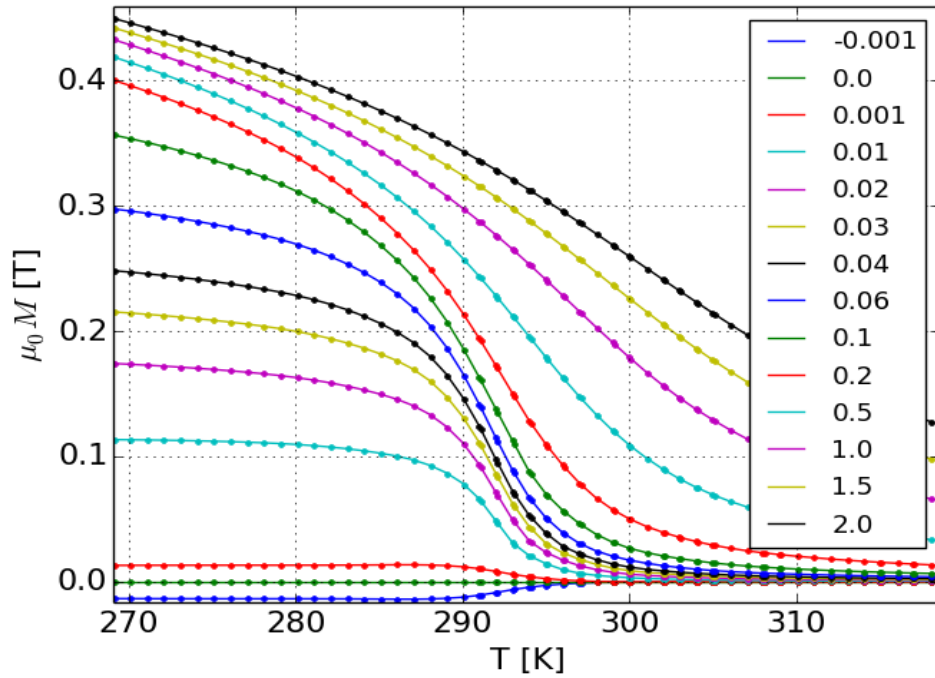
$$COP = \frac{Q_{cold}}{-Q_{cold} - Q_{hot}}$$

$$Q_{cold} + Q_{hot} = \int_{(2),(4)} c_H(T, H) dT$$



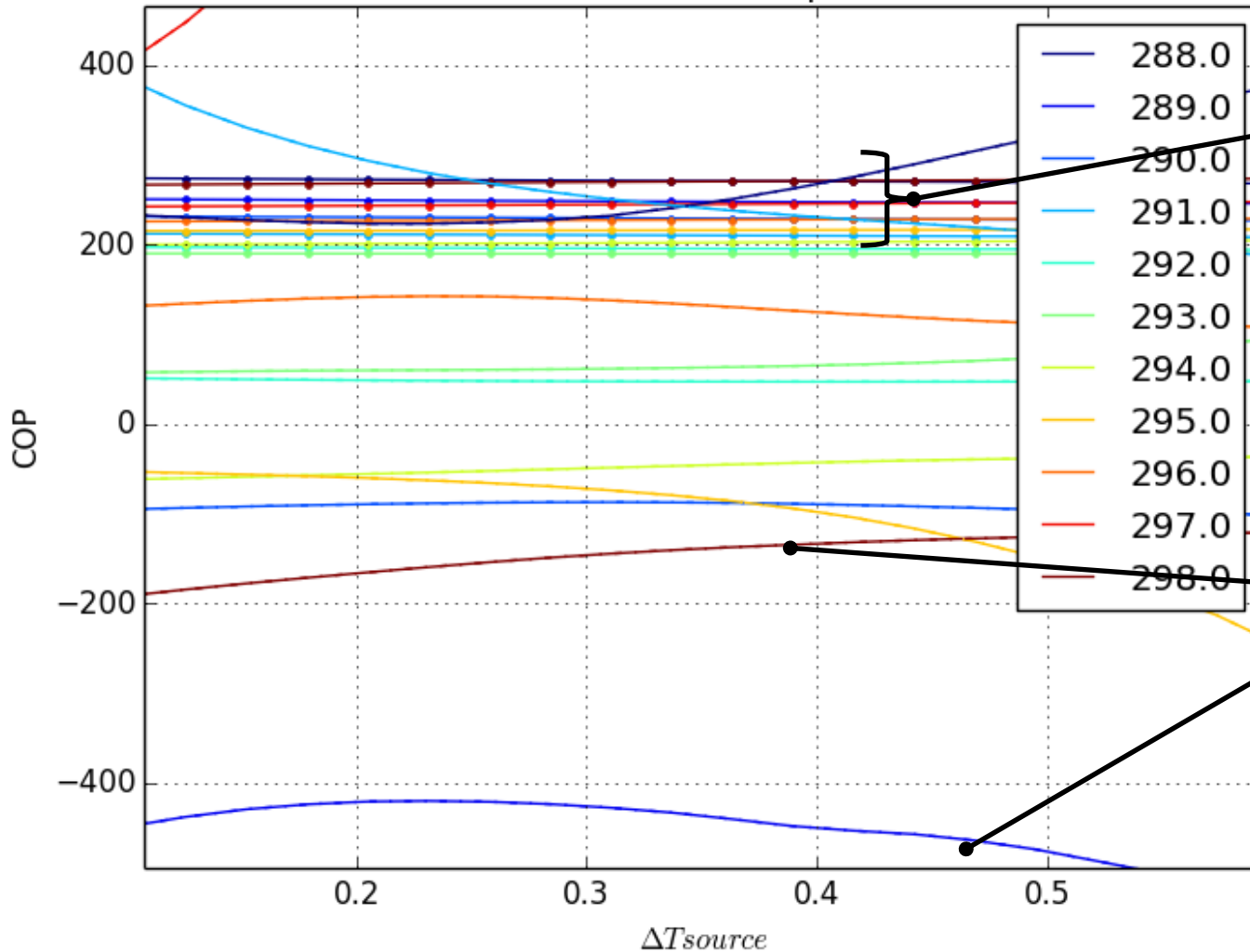
COP estimation: example

$Pr_{0.65}Sr_{0.35}MnO_3$



COP estimation: example

For different initial temperature T0



☺ Magnetic (dot)

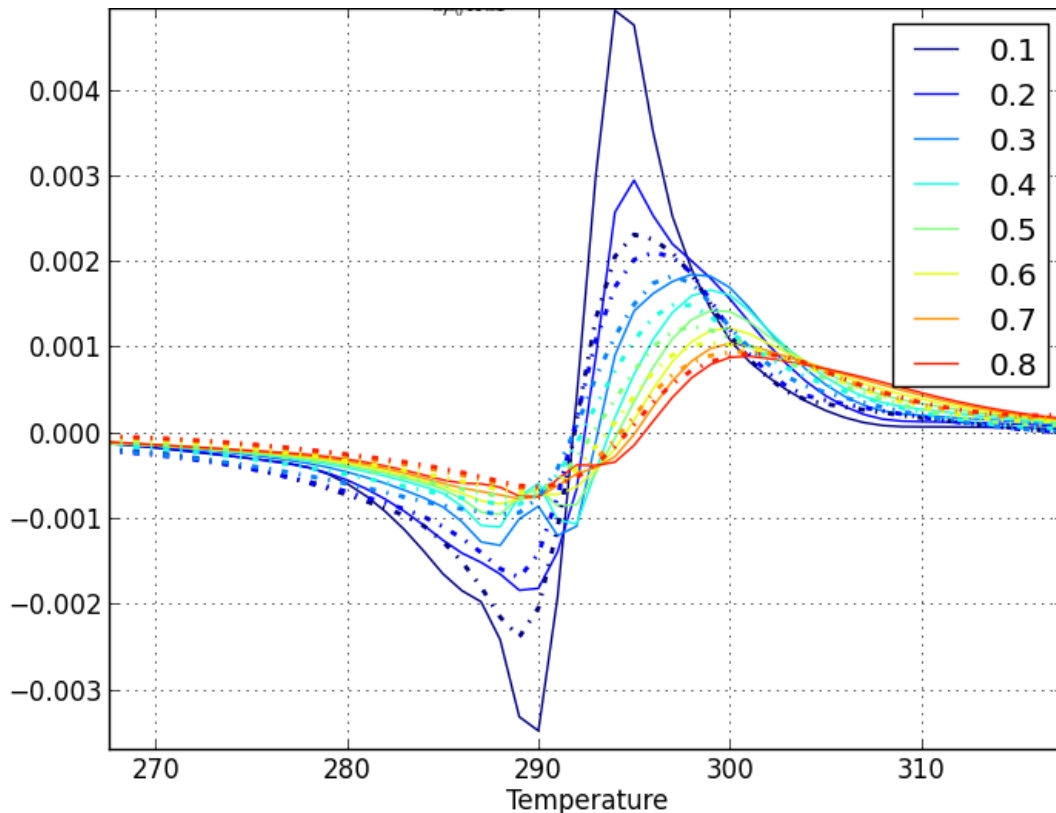
☹ Thermal (line)

Thermodynamic analysis

■ s indirectly known from $M(H, T)$ and $c_H(H, T)$

$$\partial s / \partial T = c_H(H, T) / T \quad \text{and} \quad \partial s / \partial H = \mu_0 \partial M / \partial T$$

$\Rightarrow \partial s / \partial T$ and $\partial s / \partial H$ derived from s ? \Rightarrow test by cross second derivative



$$\partial\left(\frac{\partial s}{\partial T}\right) / \partial H \text{ in dash}$$

\neq

$$\partial\left(\frac{\partial s}{\partial H}\right) / \partial T \text{ in line}$$

$\Rightarrow c_H(H, T) / T$ and $\mu_0 \partial M / \partial T$ are not exactly derived from s

■ Better to write

$$\underbrace{c_H(H, T)}_{\left(\frac{\partial s}{\partial T} + \epsilon_1\right)} dT + \underbrace{\frac{\partial M}{\partial T} \text{ measured}}_{\left(\frac{\partial s}{\partial H} + \epsilon_2\right)} dH = ds + \boxed{\epsilon_1 dT + \epsilon_2 dH} = \frac{\delta Q}{T}$$

$\Rightarrow \delta Q/T$ is not a close differential form

■ COP is ill-conditioned

$$-Q_{cold} \cong Q_{hot}$$
$$COP = \frac{Q_{cold}}{-Q_{cold} - Q_{hot}}$$

Look for s in accordance to measurement

- Impose measurement derivation from $s \Rightarrow s$ close differential form

$$s \text{ as } \left\{ \begin{array}{l} \Rightarrow \frac{\partial s}{\partial H} = \mu_0 \frac{\partial M}{\partial T} \frac{1}{T} + \epsilon_1 \\ \Rightarrow \frac{\partial s}{\partial T} = c_H(H, T) \frac{1}{T} + \epsilon_2 \end{array} \right. \begin{array}{l} \searrow \\ \nearrow \end{array} \frac{\delta Q}{T} = \frac{\partial s}{\partial H} dH + \frac{\partial s}{\partial T} dT \quad \text{Use in model}$$

Rebuild s from M and c_H measurement

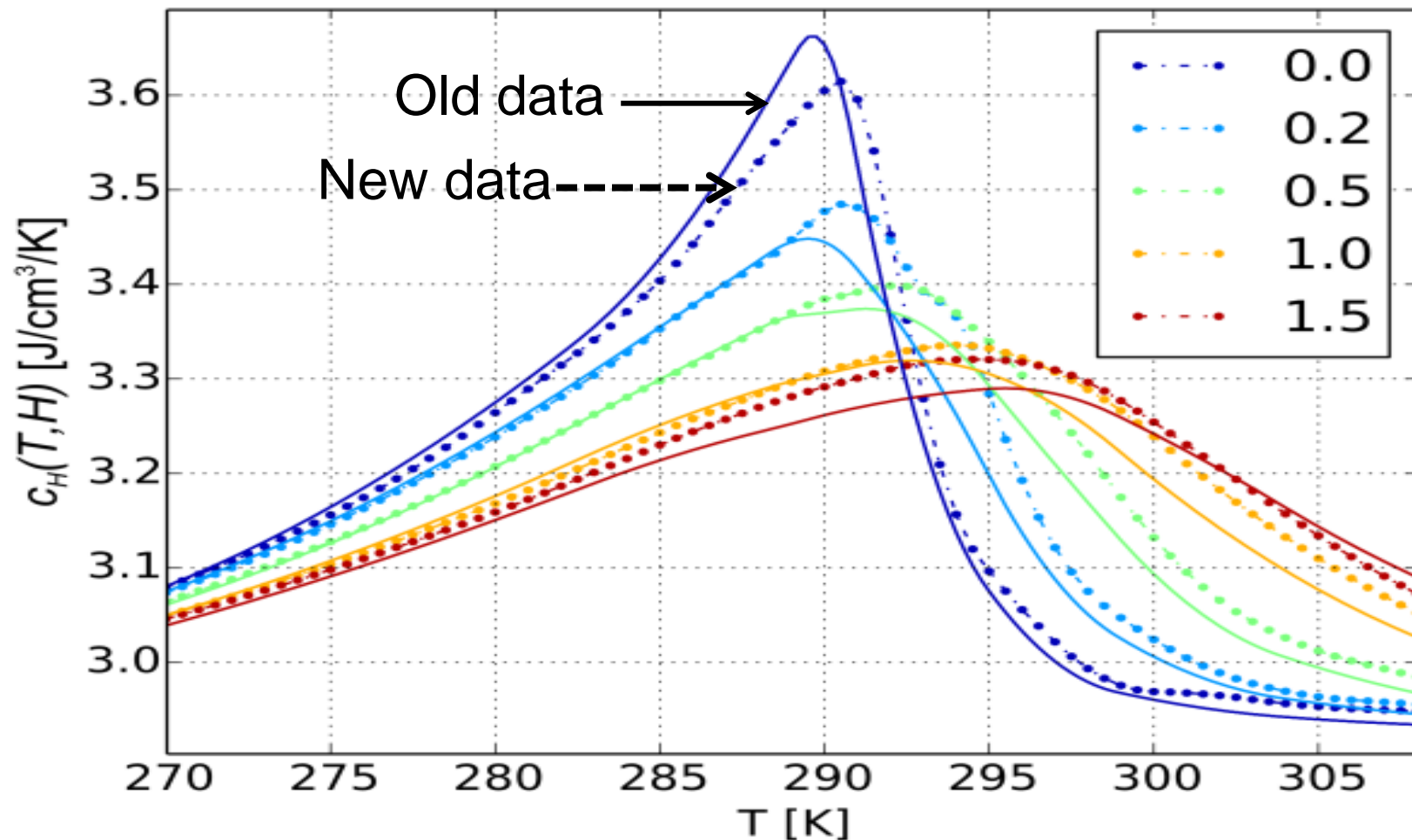
- Rebuild s as best fit data with least squares method

$$\min_s \int_{\Omega} \left\| \nabla s - \begin{pmatrix} c_H/T \\ \mu_0 \partial M / \partial T \end{pmatrix} \right\|^2 d\Omega$$

New approach: new data

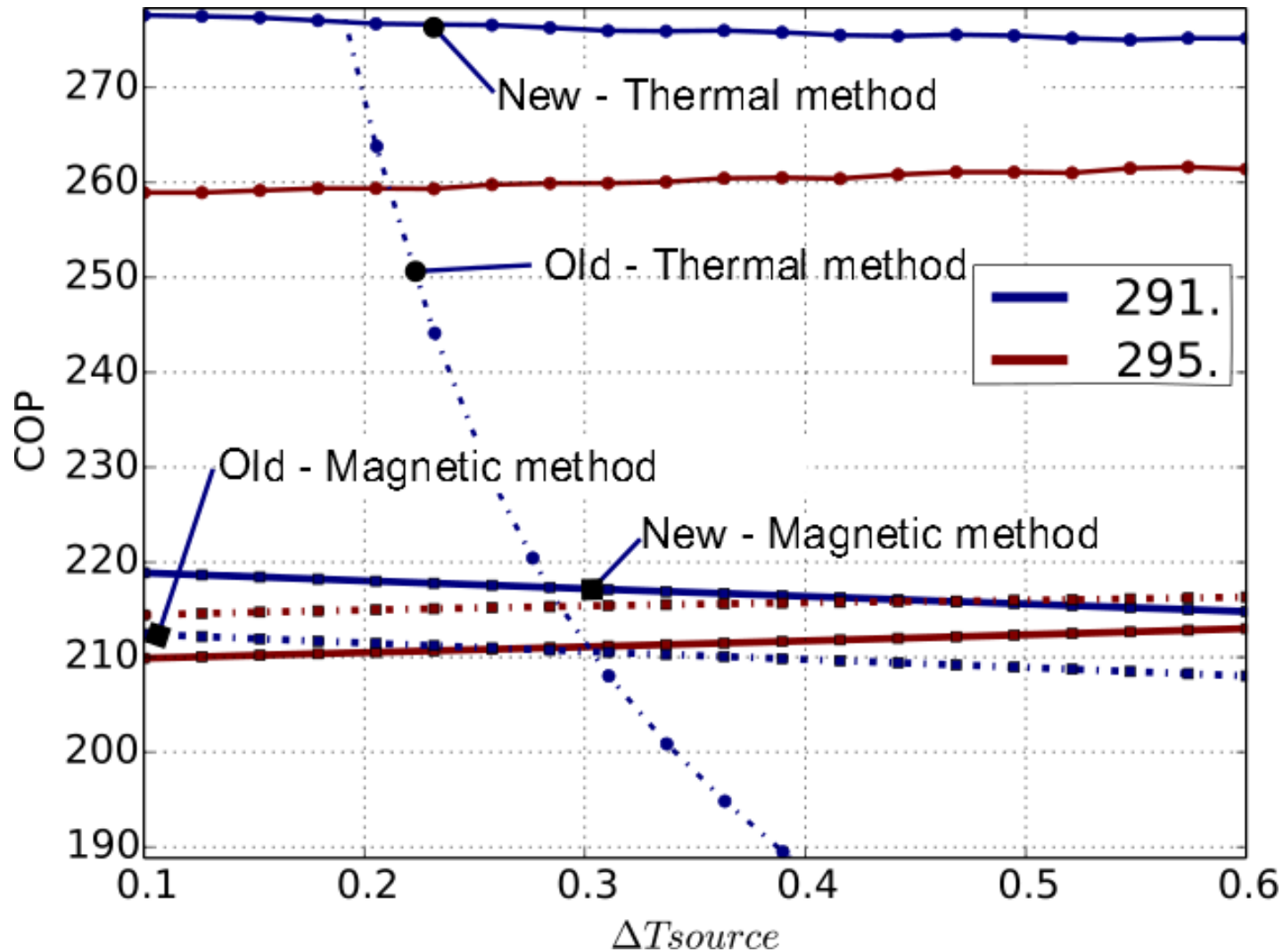
From s rebuilt, c_H and M are recomputed

- Magnetization is similar **BUT** $c_H(T, H)$ is modified



New approach: COP

- With two methods: ● **Magnetic method** ■ **Thermal method**

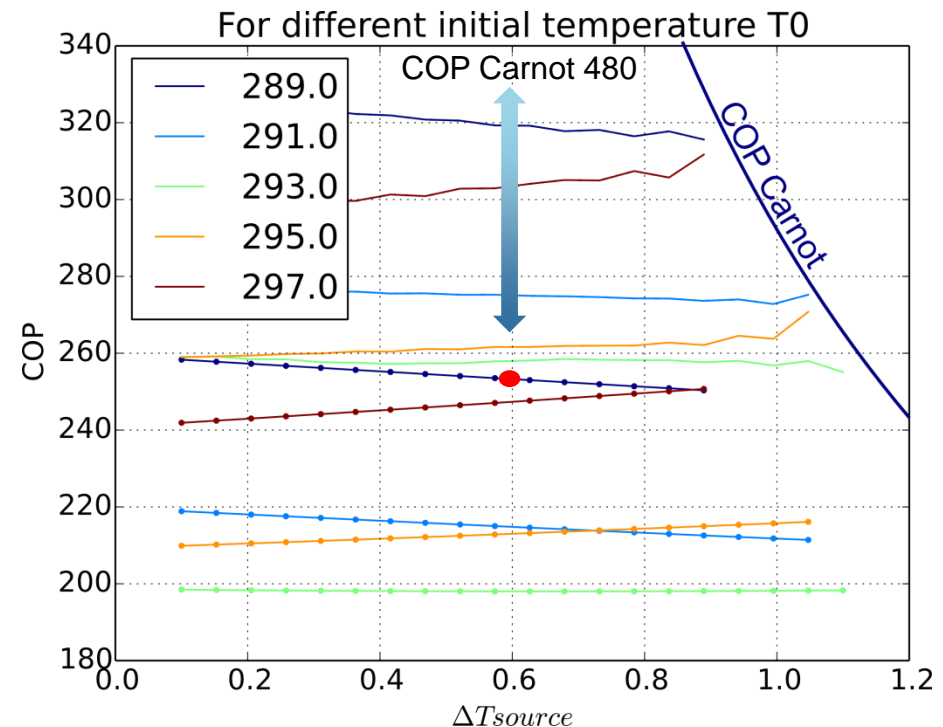
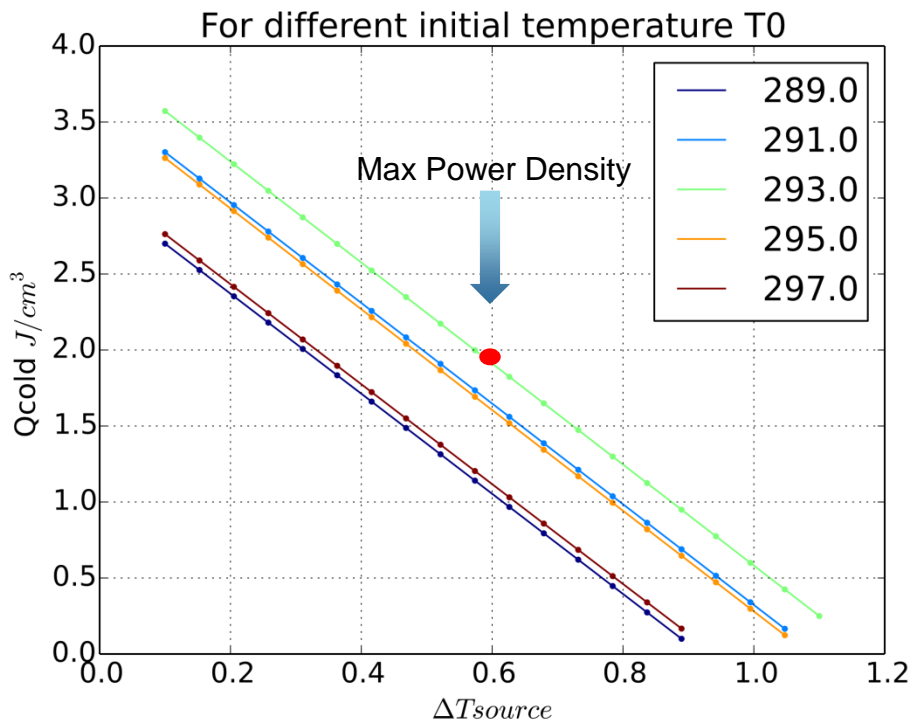


Conclusion and perspectives

Better consistent thermodynamic model

- + Improve COP estimation with heat exchange
- + Respect of energy conservation
- + Explanation of the discrepancy

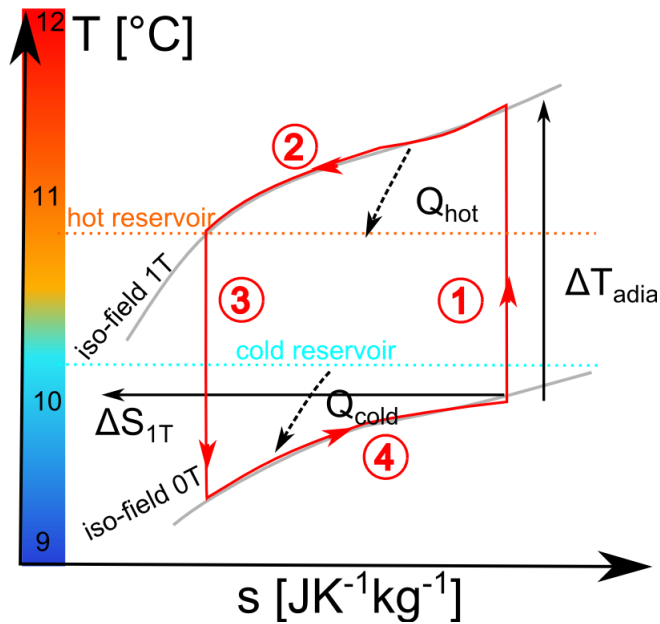
Importance of COP



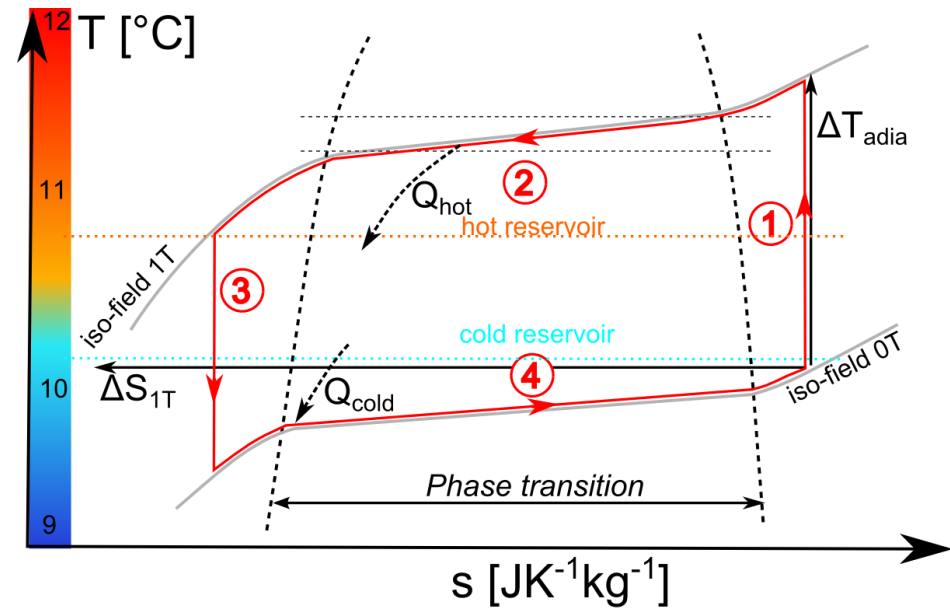
Conclusion and perspectives

Same approach on first order material

- First order phase transition => Closer to Carnot Cycle => higher COP



Second order material



First order material

- Estimation of entropy produced by intrinsic loss

Thanks for your attention



Question ?



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